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Euler: An Interactive Sound Installation

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EULER:
AN INTERACTIVE SOUND INSTALLATION

*Submitted in Partial Fulfillment of
The Prerequisite for Honors in Music*

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Wellesley College

Thesis Advisor: Jenny Johnson

Year: 2015

Foreword

I'm very grateful that my time at Wellesley has allowed me to explore multiple disciplines. Outside of my endeavors as a music major, I am also a biology minor and pre-medical student. Given my diverse background, I wanted to create and develop a thesis that reflected my various interests. I discovered the thrill and freedom of electronic music in my junior year and decided to challenge myself by expanding my knowledge of electronic composition by building an interactive sound installation for my senior honors thesis.

This sound installation is an expansion of my project from junior year, "Euler". The initial project was an exploration of the intersections present between math, music, and nature. I found with continued investigation that these three aspects are intrinsically connected, which can be shown musically through careful compositional techniques. My idea was successfully realized through new compositional techniques afforded by branching outside of the constraints of traditional composition. Electronic music allows precise placement and digital manipulations of sounds, allowing creativity while maintaining mathematical precision. This is incredibly important when the sounds themselves are rather atemporal or wouldn't be able to be traditionally orchestrated. Using sounds recorded from nature, I had my "notes" to form my composition, and my responsibility was then the same as any other composer: create something that evokes thought or emotions from sounds.

The composition I premiered at my junior year recital was obviously grounded by my classical training. I had carefully orchestrated the sounds from nature so that they followed a form, just like any other classical composition. But while classical

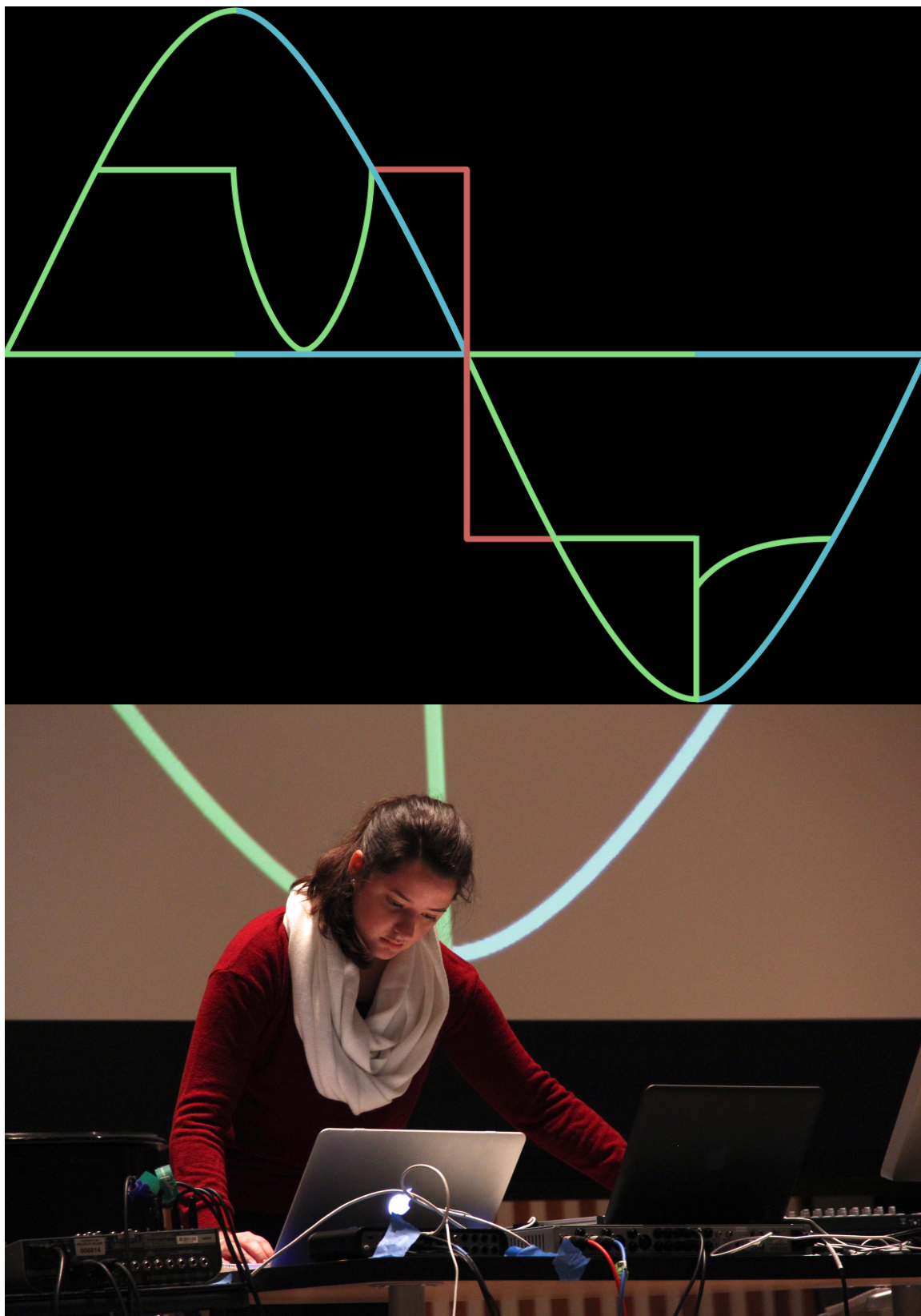
compositions have established forms to follow like ternary and rondeau forms, electronic music doesn't have established rules. Electronic music has always been about pushing the boundaries, whether it is the boundaries of technology or of what we consider to be musical. However, I didn't feel I was pushing my personal boundaries far enough. While many of the original aspects of this proto-version of "Euler" still exist, there was something missing from its performance. Its performance was too akin to how I would've performed a Bach flute sonata—the audience watching the musician communicate what the composer dictated. What if I released my control as both a composer and performer? What if in the spirit of scientific exploration, I allowed the audience to experiment with the sound environment I provided?

Now at this stage, I'm passing the proverbial baton to the audience so they themselves can be composers and performers. It's been an interesting exploration on my own part to try and construct something that would provide the tools and means to do this by building an interactive sound installation that surrounds the user in a rich sound and visual space.

A sound installation by definition invites a cross-disciplinary approach. It combines the aural aspects of musical composition, while also creating a visual space to perform your composition. My general vision was to allow users to enter and explore a space, uniquely triggering sensors, and, in turn, affecting the sounds they hear. These sounds range anywhere from indistinguishable digital tones to the rich microcosm of various natural settings. To seal off the area as a soundscape, polystyrene walls create a sense of isolation from the outside world as the users focus and explore the space. Electroluminescent lighting shows the "paths" of force sensitive resistors that people can

follow as a general guideline, but they can of course deviate from that path, creating their own unique soundscape. With each of the electroluminescent lighting strands intersecting at the focal point of the enclosed structure, I hope that users will approach the center of the installation to hear the “base” of nature, hence why this project is called “Euler” for e , the base of the natural logarithm. This project has been the culmination of what I have done at Wellesley, merging my various academic and personal interests in biology, music, and technology together into something tangible that hopefully many people can enjoy and experience.

EULER: LIVE



Roots and Fundamentals

As a musician, one pays close attention to sounds, likely more than the average person. In the context of performing, you're trained to listen to your own sound, and if in a group, trained to listen to the sounds of others. You begin to constantly analyze sounds. You pay attention to the presence and absence of sound including the timing and dynamics of sounds. You become aware of pitches, their tuning, and their intervallic relationships to other pitches in the hierarchy of the overtone series. Soon it becomes second nature to constantly be contemplating these things while performing—it's a necessity.

Performing music well necessitates this concept of musicianship, which is much more complicated and abstract than simply paying attention to and interpreting sounds; it is infuriatingly hard to distill into a couple of phrases. Musicianship requires creative thought and opinions. It is informed through experience and knowledge of musical theory, history, and harmony. It requires communication and compromise between musicians and the audience. I've contemplated greatly what distinguishes a sound from music, and I initially believed this abstract notion of musicianship touched on the surface of the determining factor between the two. However, attempting to label this as a distinguishing trait was incredibly biased towards my classical performance history.

Notably in the 20th Century, the traditional practices, harmony, and performance of music underwent a radical deconstruction, which is still underway today in many circles. As I continued my musical education I learned of various composers who rejected the traditional notions of harmony and tonality. Many schools of thought arose as to how to best achieve this goal, and I personally gravitated towards musique concrète and

serialism. The latter became a more general inspiration for my work, as I drew on very general ideologies from serialism but wanted to apply those concepts using a different sound palette, which was inspired by musique concrète.

Form

Serialism is often associated with Arnold Schoenberg's twelve-tone technique, which effectively deconstructs conventional harmony by straying from our familiar diatonic scale and chord structure. The twelve-tone technique dictates that each of the 12 notes of the chromatic scale must be used in equal frequency and in a particular order to form a tone row. While I wasn't drawn to serialism's harmony, or lack thereof, the methodical approach to composition intrigued me. A matrix defines all the allowed variations on a chosen tone row through inversions, retrograde, and retrograde inversions, which affect the order in which the notes can be played. It was a stark contrast to the compositional techniques I was familiar with, which had its own set of harmonic rules but was much less rigid, allowing for creative bending of the rules to add "color" to the sound. This was much more mathematical and systematic.

The piece I premiered at my junior recital was fully composed, with planned timings, entrances, and manipulations by myself. The structure of the composition was inspired by a sine wave, hence the logo designed for the background during its performance. The logo itself parallels the form of the piece, with reaching a climax before the halfway point, in which the composition begins to mirror itself for the latter half, and ultimately returns to its origin, allowing it to be a potentially infinite cycle of sounds.

I found myself particularly interested in musically mimicking a sinusoidal form due to basic sound synthesis practices. In my electronic music class, we built several “patches” in a program called PureData, which emulates an analog synthesizer by connecting digital patch cords to certain modules. One of the first patches we built was connecting an oscillator set to 440Hz (~osc 440) to a digital-to-analog converter (~dac) to produce a sine tone at a frequency of 440Hz, known to musicians as “concert A” pitch, our ubiquitous tuning note in orchestra. This first introduction into sound synthesis not only influenced the musical form, but also the duration of the cycle.

The same semester I was in my first sound synthesis class I was also taking Comparative Vertebrate Anatomy. Two mathematical concepts recurred throughout our discussions of physiology—the surface area to volume ratio and fractals. In particular, the latter interested me greatly. Fractals are present in many physiological systems, such as the respiratory, circulatory, and nervous systems. Bifurcations are present in the pulmonary system as the bronchi split into bronchioles; the coronary system has the aorta splitting into various arteries, then into arterioles, then into capillaries; neurons’ dendritic structure resembles that of a tree. Obviously these fractal bifurcations are present outside of mammalian physiology, notably when considering the aforementioned branching structures of trees and other plants. The omnipresence of fractals in nature intrigued me, so I looked into the math behind it, which led to me discovering the first Feigenbaum constant. The first Feigenbaum constant, δ , which is an irrational number equal to approximately 4.669, is the limiting ratio of each bifurcation interval. Noticing the parallels between sine waves and fractal bifurcations both having periods, I decided to see how long 4.669 minutes lasted and found it equaled 4 minutes and 40 seconds, which

provided a nice artistic parallel to my classical background of tuning to 440Hz. Thus I had decided on another aspect of my composition's form—the duration of the cycle.

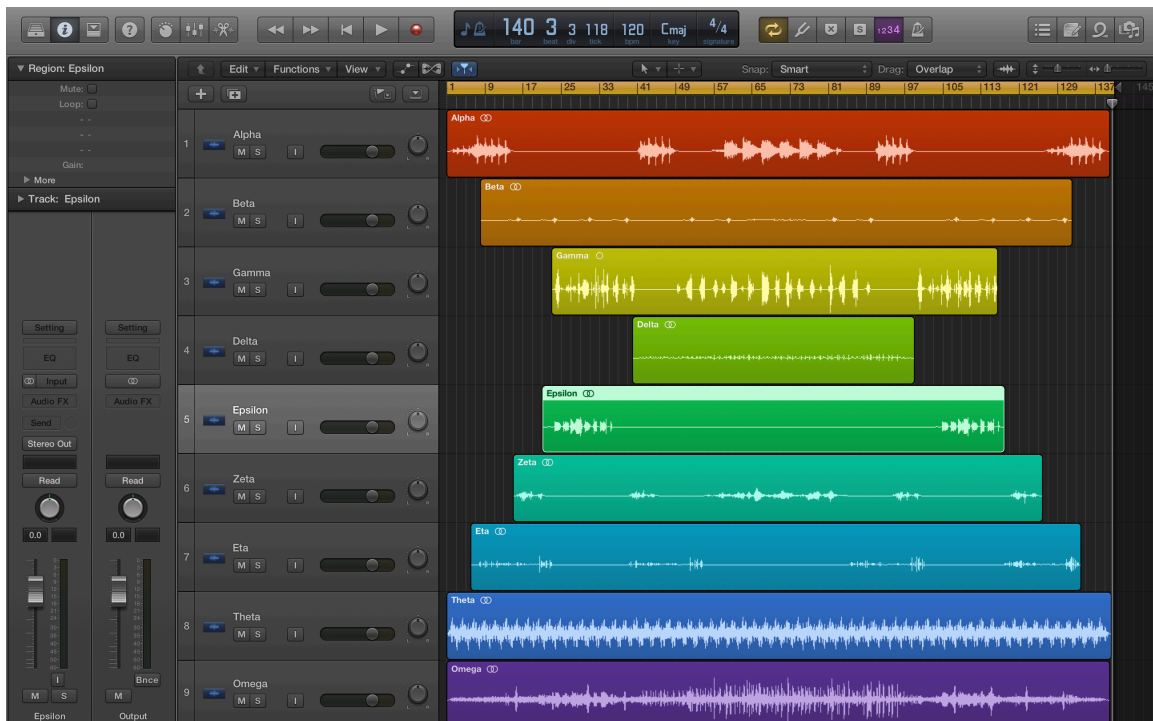
Sound

I decided I wanted to explore the boundaries of sound and music in my composition to challenge not only my own notions but also to challenge my audience's perspective on what was musical. The first project in my sound synthesis class exposed me to *musique concrète*, which is characterized by using recorded sounds as raw material for a composition. My *musique concrète* project consisted of recordings of turned pages, a fan, plucked piano strings, rubbed crystal glass, and carbonation from seltzer water, the last of which was recorded using a piezo element instead of a traditional microphone. It was a great way to break from the homogeny of my previous compositional experiences using conventional sounds to create something musical, and I wanted to build off of that but in the context of exploring the intersections of math, music, and nature.

I began to pay close attention to sounds of various natural elements, abiotic and biotic alike. I discovered that sounds from nature have a hierarchy just like how traditional instruments have a hierarchical role in composition. Abiotic sounds that we typically don't pay much attention to, like that of wind or rain, create a nice background texture to set an atmosphere to the piece. Other abiotic sounds, like thunder, are great at punctuating and accentuating moments since they draw our focus. Some biotic sounds like insects that produce a constant, steady pulse, for instance crickets or cicadas, are like percussion instruments keeping a steady beat. Biotic sounds notable for their communication, like birdcalls or whale songs, tend to be more traditionally melodic. It

was with this in mind that I had my “notes” for my composition and had begun to draw the connection between music and nature.

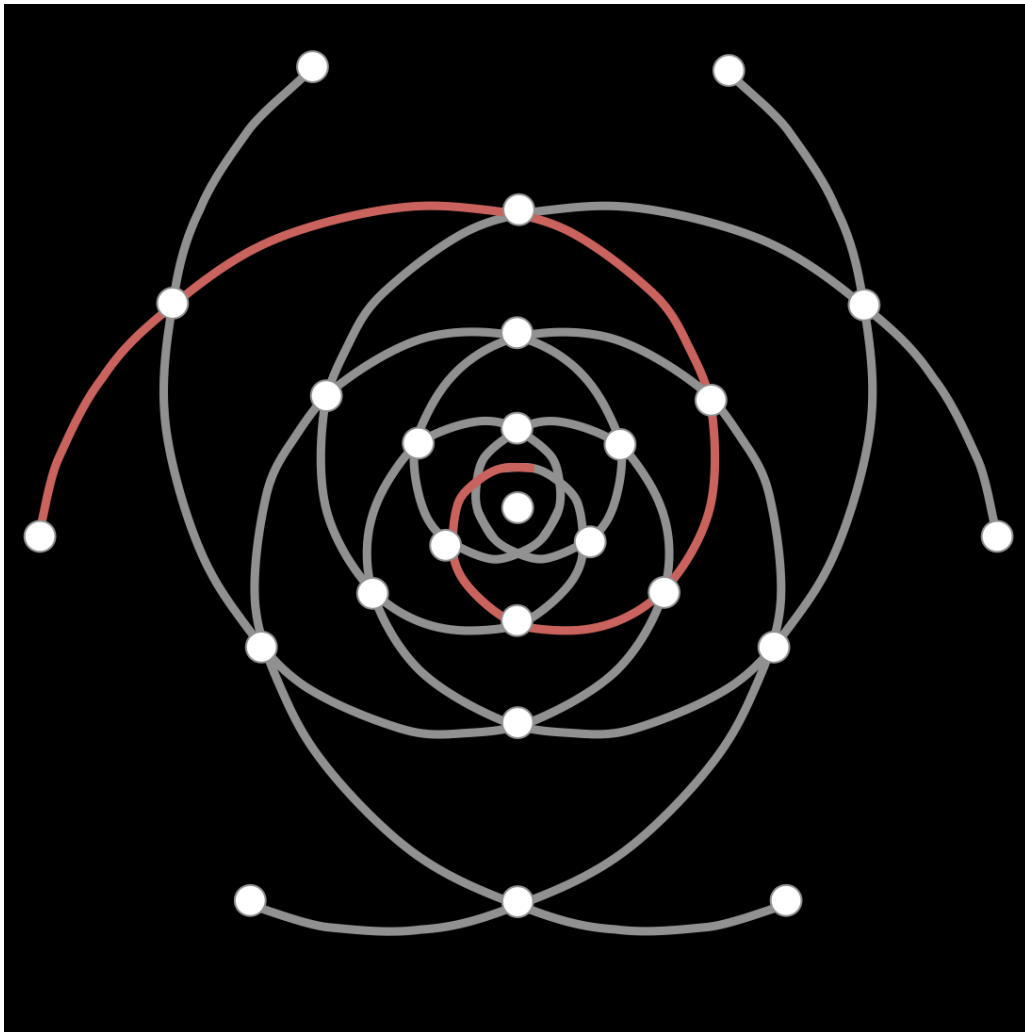
Seeing as I wanted to connect this back to math, I drew on the idea of the sine wave once again. A sound in its simplest form is just an oscillation of air molecules and can be synthesized by a waveform generator supplying adjustable AC current to a set of speakers. The simplest and most recognizable tone is that of a single sine wave, devoid of the complicated overtone series we hear when an instrument plays a single note. I decided to try and transform these sounds from nature using digital processing to try and compress these rich sounds into something emulating the mathematical pure tones of simple waveforms like that of a sine, triangle, square, or saw tooth wave.



Performance

After carefully orchestrating the sounds using Logic Pro X, I formulated a way to allow myself to easily control the level of digital processing on the sounds. By attenuating the amplitude of the processed versus unprocessed sound, I could control the level of unnatural versus natural sound the audience heard, but that was difficult to control live. I went ahead and divided groups of sounds into individual tracks so that I had eight tracks to control, with one constant track, which was that of a heartbeat. By compartmentalizing groups of sounds, I could control which kinds of sounds I wanted to add processing to at will, for instance processing my birdcall melody while keeping the thunder clap unchanged using sliders on a MIDI controller.

While I achieved the effect I desired, I felt something was lacking. I felt I had explored the intersections of math, music, and nature, and I even felt that I was able to communicate that to some degree to my audience. However, I wanted the audience to enjoy the thrill of self-exploration, and to do that, I had to give up my autonomy as a composer and performer. Being the composer puts you in a place of power where you dictate what happens and why it happens, and you become accustomed to that unbalanced hierarchy of you and the audience. Giving up that musical control would be a thrilling and challenging experience as I tried to design a way allowing anyone to experience something akin to scientific discovery in music.

EULER: AN INTERACTIVE SOUND INSTALLATION

In early childhood, there is a constant hands-on exploration of the surrounding environment. An infant can't read a book about the world and can only grasp the most basic concepts via vocal communication until later. I fondly remember the wonder of childhood, where I was constantly learning something new about my environment by interacting directly with it. I wanted to reproduce this method of query and discovery for my audience and settled on transforming my live compositional performance into an interactive sound installation.

While I knew I could draw on many of the same concepts of the live version of Euler, some core elements would no longer work, specifically my decisions on precise mathematical timings informing my orchestration. If I was going to allow the audience to control the sounds, I couldn't simply let them control the amount of processing. They could've just walked on stage where I was standing and fiddled with the sliders as I was, but there would be little to no exploration. I had to completely revamp my thoughts on how to connect the three disciplines.

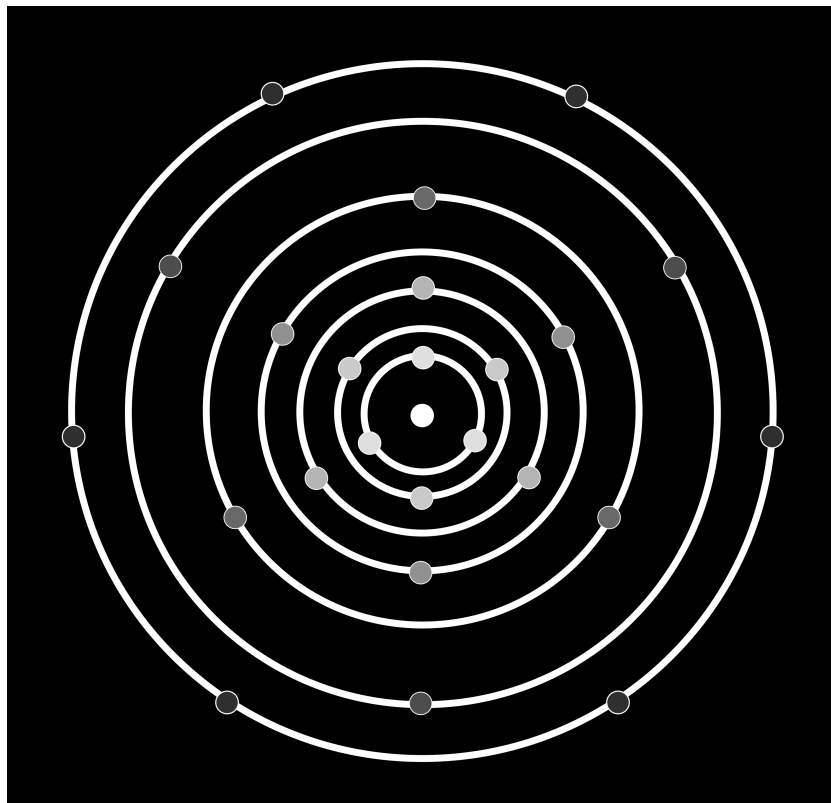
Sound Design

Since I was no longer using a MIDI controller, I had to think of a new way for people to control the triggering and processing of the sounds. I explored various kinds of sensors, including infrared sensors, flex sensors, ultrasonic rangefinders, photocells, and force sensitive resistors. After testing each of these extensively, the force sensitive resistors were the most resilient and consistent sensors to trigger the sounds.

Instead of focusing on the sine wave, I looked more into the golden ratio and its presence in nature specifically as the Fibonacci spiral. There are many natural occurrences that take the form of the Fibonacci spiral; notable examples include the shape of hurricanes, the spiral arrangement of leaves in certain plants, and shape of snail shells. It is from the Fibonacci spiral that I drew the inspiration for the layout and design of the installation. Twenty-four force sensitive resistors line the array of six intersecting Fibonacci spirals with a final force sensitive resistor located at the center of the array. This array fits a 9' x 9' square foot area, so that people can walk around the space triggering the sensors as they explore the area, which is enclosed by polystyrene walls but

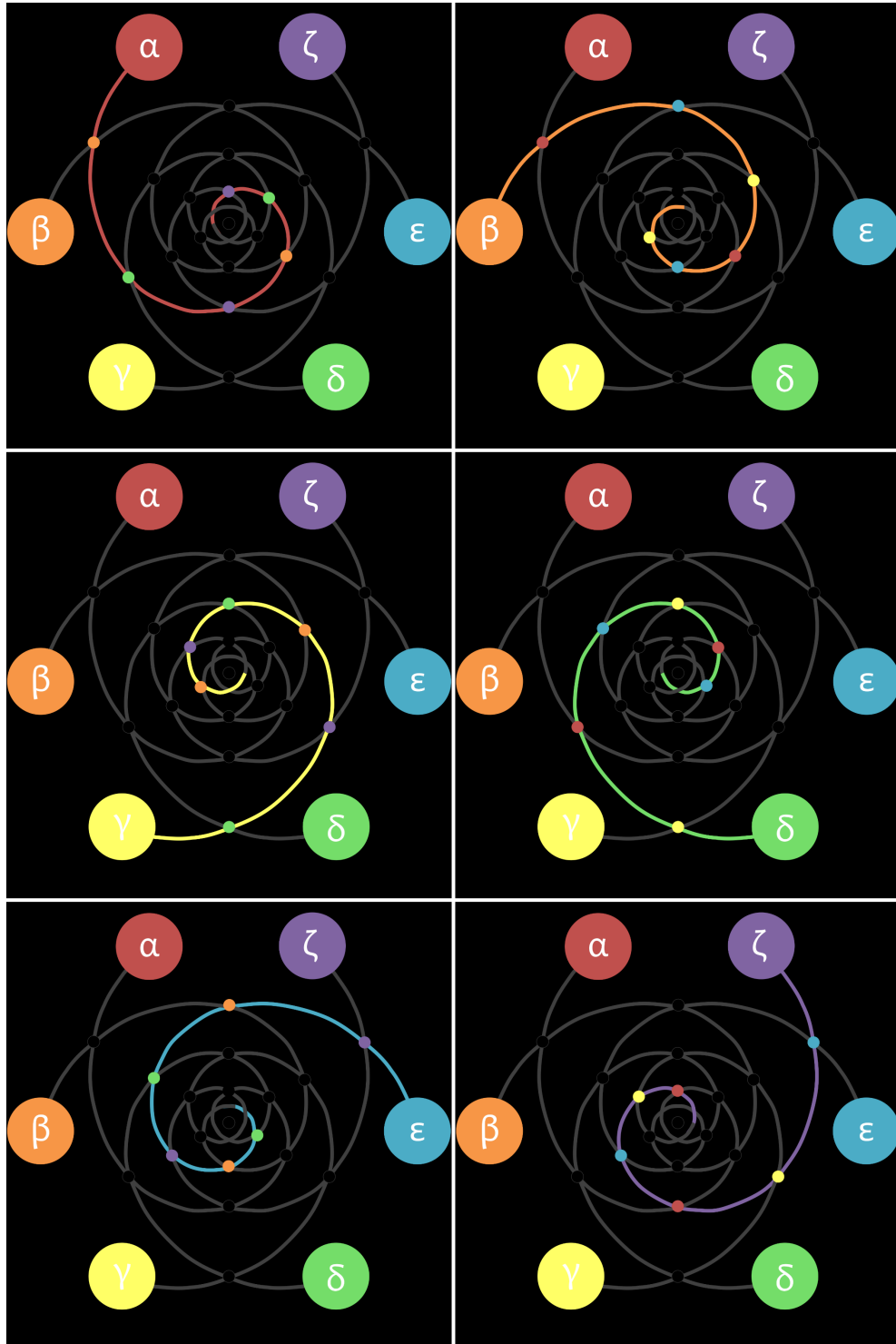
open above, allowing natural light to enter the space. The Fibonacci spiral paths are lit by electroluminescent wire, which also illuminates the space and reflects the dichotomy between the natural and digital realms present in the sounds.

On the outside of the array the sounds are completely processed, and as you approach the center the level of processing reduces and the natural sound of the recordings slowly reveals itself until you reach the focus of the array. The diagram below shows rings connecting the force sensitive resistors delineating each zone of processing levels, where the circles get lighter in color as processing decreases.



Each of the paths, which are labeled alpha through zeta, has a set of associated sounds so that each has a unique sound microcosm that contributes to the sound environment as a whole. When one of the paths intersects with another, the two unique microcosms combine to create a hybrid sound. This is better illustrated below, where the

color of the path matches the origin, and the force sensitive resistor circles are colored to match the path that is being blended with the origin path.

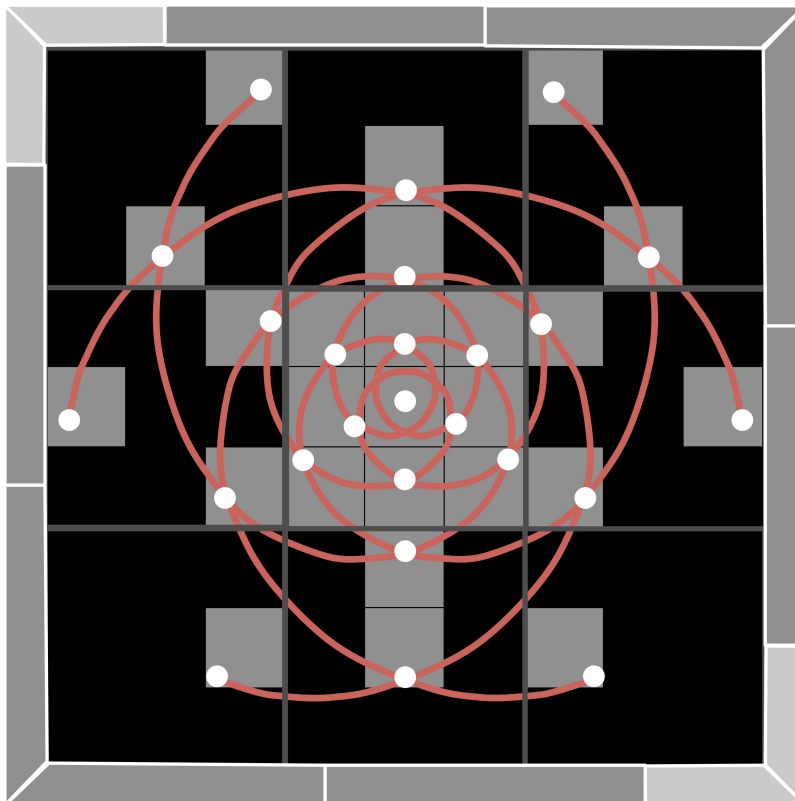


This setup allows for the user to hear possible combinations at two different levels of processing before approaching the center force sensitive resistor, which plays each of the paths' sounds in their raw, natural state concurrently. The combinations are also illustrated in the following diagram, which additionally shows that at the first force sensitive resistor of each path, it is purely the sound of that single microcosm, while the rest are hybrids.



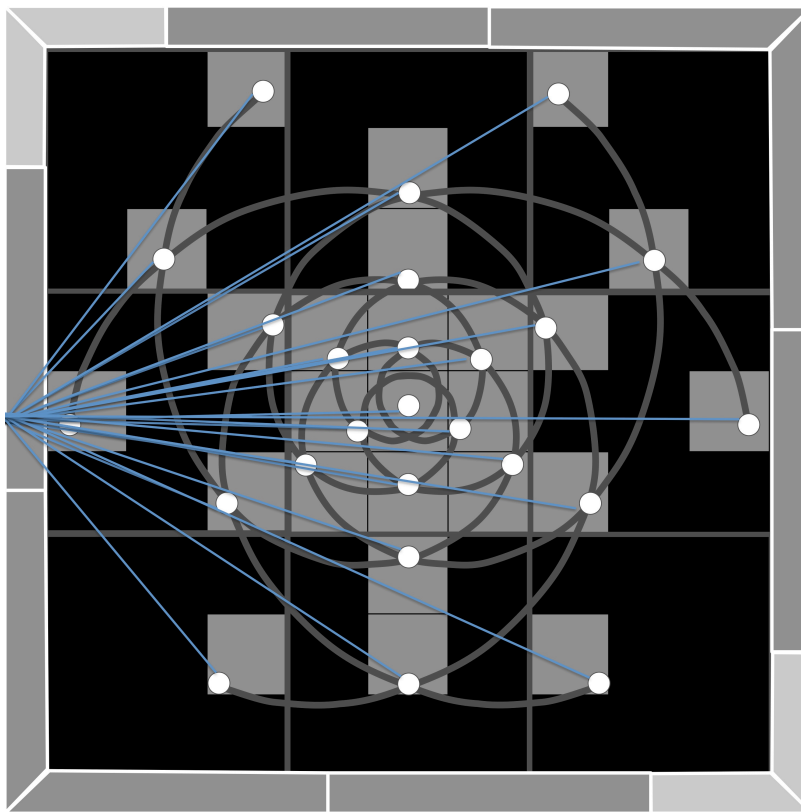
Structural and Digital Design

The force sensitive resistors are protected underneath nine sheets of acrylic that are 3' x 3' in dimension. The force sensitive resistors are arranged so there is one force sensitive resistor per one square meter in order to avoid inadvertent activation by proximity to other sensors, which is shown in the following schematic. The electroluminescent wire outlining each path is also protected beneath the acrylic flooring. The polystyrene sheets, held together by metal brackets, surround the interactive flooring, enclosing an area 10' x 10'. The individual sheets are 4' x 8' in dimension, and some were cut in half, which are represented by the lighter grey boxes for the corners of the structure.

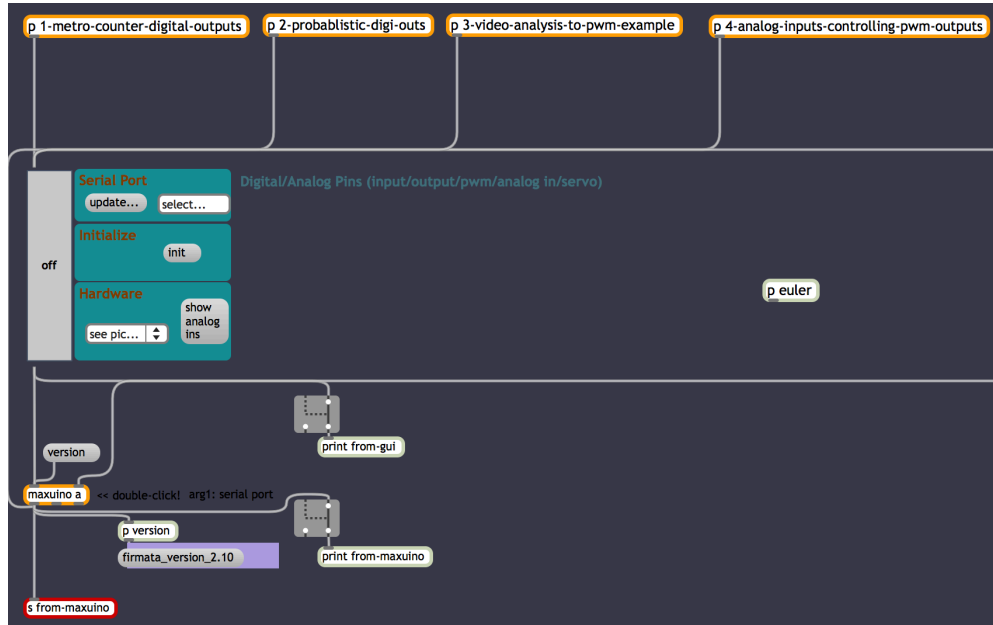


When the force sensitive resistors are stepped on, the serial output goes from infinite resistance to zero resistance, which communicates to the computer running the

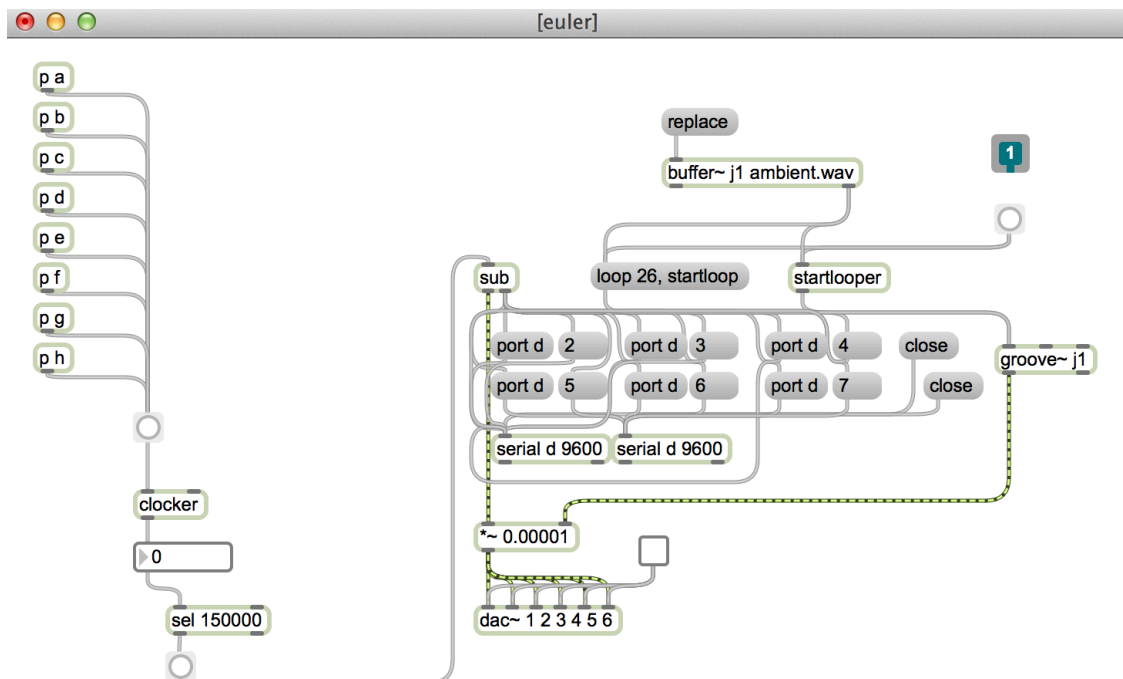
installation via a microcontroller called an Arduino. The Arduino controlling the force sensitive resistors is an Arduino Mega, which has enough digital input ports to receive data from each of the sensors. The Arduino then communicates with a program on the computer called Max/MSP, which controls the sound levels and transitions of each sound clip used, which was designed in Logic Pro X. The optimal way to wire the force sensitive resistors to the Arduino Mega to use the least amount of wire (blue lines) is shown below.



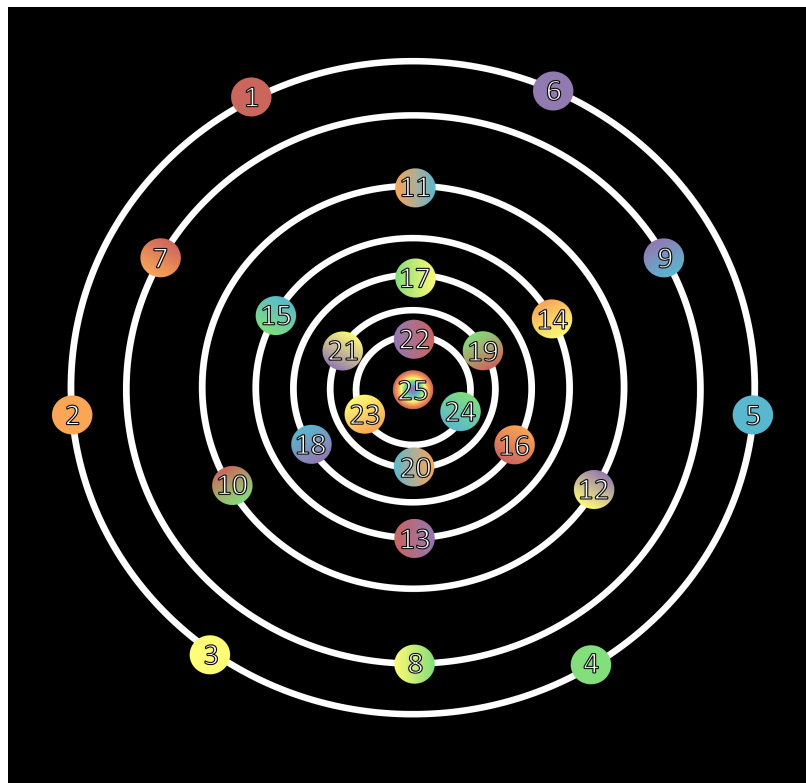
Two other Arduinos, this time Arduino Unos, have protoshields on them called Escudo Dos, which allow the electroluminescent wire to be controlled by Max/MSP to light up when a force sensitive resistor on that path is activated. Provided below are screenshots from the Max/MSP patch which controls the installation.

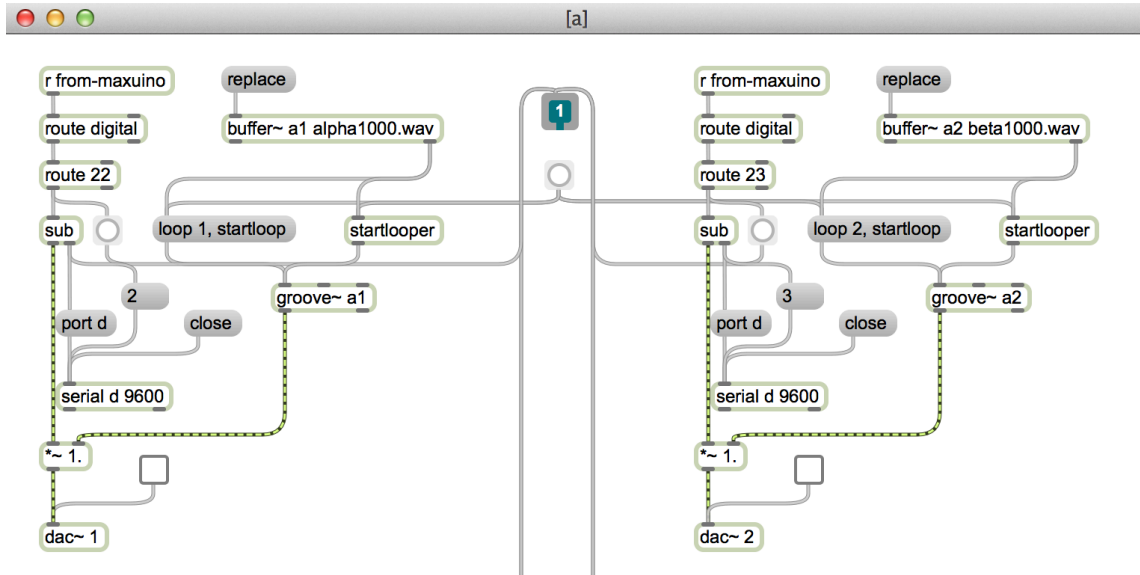


Above is the Maxuino interface, which allows the initialization of the Arduinos to receive information from the force sensitive resistors and relay it back to Max/MSP to trigger the audio samples. Below is [euler], the highest level patch, which contains several subpatches, designated by a “p” prior to the subpatch name, which control specific parts of the installation.

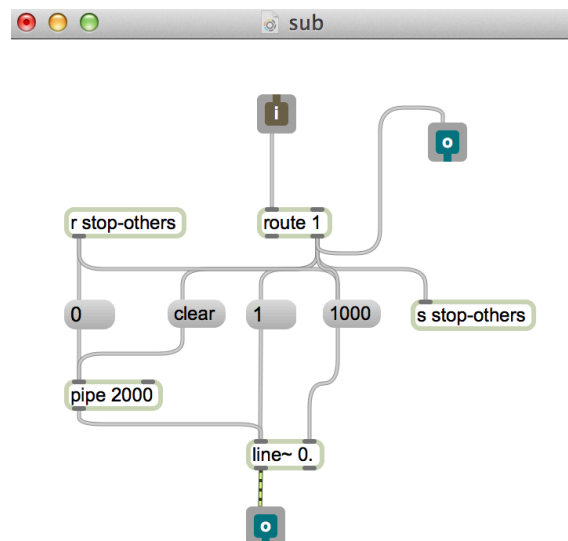


The [euler] patch is the most complicated of the patches since it relays back signals from all the 25 sensors and has additional logic built into it to activate an ambient track when the sensors inside the installation haven't been activated for 2.5 minutes. The subpatches [a]-[h] take in the signals from the force sensitive resistors, so that [a] corresponds with the sensors in the outermost ring in the diagram below, and each successive ring corresponds to a different subpatch and different sensors.





Above is a portion of the [a] subpatch, as the rest of the patch mirrors this format for the rest of the sensors. The [a] subpatch controls the most force sensitive resistors (6), while subpatches [b]-[g] control three sensors, and the last subpatch [h] only controls the middle force sensitive resistor. Each of these subpatches is identical in that they receive a signal from the Arduino [r from-maxuino], recognize it as a digital input [route digital], know which port to be expecting the signal from [route xx], which leads to the [dac~] and [sub] subpatch shown below.



The [dac~] command is responsible for the sound getting sent to one of the six speakers positioned at the origin of each path. Depending on which paths are activated, their respective speakers will be playing the sound file so that the audio is spacialized throughout the installation. The [sub] subpatch is responsible for attenuating the sound when a sensor is activated or deactivated so that there is a cross-fade while the audio transitions. Connected to the output of [sub] are the commands to the other Arduinos controlling which electroluminescent wire is lit.

The audio file is opened from the computer using [replace] and [buffer~ filename.wav] which feeds into [groove~] and [startlooper]. These two latter functions are responsible for looping the sound files when someone is interacting with the installation longer than the 4:40 minute cycle. The processed audio files are saved beforehand at the various levels necessary coordinating to each force sensitive resistor so that the computer doesn't have to do live audio processing and can dedicate its RAM to consistently execute the patch properly.

Emergent Thoughts and Acknowledgements

I look forward to people interacting with my installation and exploring the soundscape I have built digitally and physically. I can only hope that it will be a valuable, and at the very least unique, experience of musical, mathematical, and scientific discovery. There are many people I must thank for making this monumental endeavor possible. Firstly, I wish to thank Jenny Johnson, my thesis advisor, for introducing me to this whole realm of electronic composition and sound installations. I wish to thank those on the board who awarded me the Jerome A. Schiff Fellowship to fund my thesis. I wish to thank the Music Department for providing additional funding to make this dream project of mine come to fruition, and thank you, Magdalen Christian, for always helping with my various requests. Without the kindness of Sarina Khan-Reddy at the Davis Museum, there would be no computer to run the installation. My sincerest thanks go to Kaća Bradonjic in the Physics Department for giving me artistic and electrical feedback throughout this process as well as helping me find a space to install my thesis. Thank you, Michele Waters, who provided professional assurance that my thesis shouldn't burn down due to electrical issues. And to my friends who have stood by me before and through this hectic year: thank you, Tyler Dixon, for helping me navigate the tumultuous waters of debugging code; thank you, Amelia Winter, for lending an open-ear and support while I voiced my frustrations and concerns about the whole process; and finally thank you to all my friends who helped me transport materials across campus and kept me company throughout the build process.